Adaptive Radar Pulse Compression

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Introduction: Pulse compression enables a radar to achieve the high range resolution of a short pulse without the need for high peak transmit power via the transmission of a modulated long pulse (or waveform) followed by its subsequent matched filtering upon reception. However, the matched filtering of large target returns produces sidelobes that can mask the presence of smaller nearby targets. A pertinent example of this is in landmine detection by ground-penetrating radar in which the ground return can mask the presence of a mine.

The Radar Division has recently developed an approach denoted as Adaptive Pulse Compression (APC) whereby the radar receiver matched filter is adapted to the received signal using a novel variation of Minimum Mean-Square Error (MMSE) estimation. By adapting the receiver filter to the received signal, the sidelobes resulting from large targets can be suppressed to the level of the noise, thereby greatly increasing the radar's sensitivity to smaller targets.

Adaptive Pulse Compression: The range profile illuminated by a radar can be modeled as an impulse response whereby each sample represents an individual range cell, with a range resolution that is inversely proportional to the bandwidth of the transmitted waveform. As such, the received signal is effectively a convolution of the waveform with the range profile impulse response that is to be extracted from the received signal. The application of the standard matched-filter to the received signal maximizes the SNR of a point target in white noise but is known to suffer from range sidelobes induced by large targets, which can mask the presence of smaller targets (Fig. 1).

To suppress the range sidelobes from the large targets and thereby improve the radar's sensitivity to detect smaller nearby targets, the Adaptive Pulse Compression algorithm uses Reiterative Minimum Mean-Square Error (RMMSE) estimation. RMMSE uses the range cell estimates from the matched filter as a priori knowledge to estimate the appropriate receive filter for each individual range cell. Given the knowledge of the relative locations of large scatterers within the range profile that is provided by the matched filter, the RMMSE receive filter for each particular range cell places nulls at range offsets that correspond to nearby large targets. In so doing, RMMSE suppresses the range sidelobes induced by the nearby large targets so that the true complex amplitude of the particular range cell can more accurately be estimated. Furthermore, the refined range cell estimates obtained from applying RMMSE can themselves be used as more accurate a priori knowledge with which to repeat RMMSE and further improve the estimation accuracy. It has been found via extensive numerical simulation that 3 to 4 stages of range cell estimation (inclusive of the initial matched-filtering operation) are sufficient to suppress the sidelobes into the noise and thereby unmask any small targets. The process of alternating estimation between the range cells and the receive filters is denoted as the Adaptive Pulse Compression (APC) algorithm. As an example, consider Fig. 2 in which three stages of the APC algorithm is able to uncover the small target that was previously masked by using the matched filter. Furthermore, as an example of a stressing scenario, Fig. 3 illustrates the case of several densely spaced targets with highly disparate power levels such as might occur for a convoy with a Ground Moving Target Indicator (GMTI) radar, an airborne formation, or as a result of synthetic aperture radar (SAR) clutter imaging. In this scenario the matched filter reveals only the largest targets and masks the smaller ones. In comparison, the APC algorithm enables the detection of even the very small targets by mitigating the range sidelobes from the large targets.

Summary: The Adaptive Pulse Compression algorithm using Reiterative Minimum Mean-Square Error estimation has been demonstrated via computer simulation to substantially reduce range sidelobes resulting from the matched filtering of large target returns. In so doing, APC greatly improves radar sensitivity and enables the detection of previously masked targets. Current work is involved with the test and evaluation of APC using measured radar data, preliminary results appear quite promising.

References
[1] S.D. Blunt and K. Gerlach, "A Novel Pulse Compression Scheme Based on Minimum Mean-Squared Error Reiteration," *IEEE Intl. Radar Conf.*, Adelaide, Australia, September 3-5, 2003, pp. 349-353.
[2] S.D. Blunt and K. Gerlach, "Adaptive Pulse Compression," *IEEE National Radar Conf.*, Philadelphia, Pennsylvania, April 26-29, 2004, pp. 271-276.
[3] S.D. Blunt and K. Gerlach, "Robust Predictive Deconvolution System and Method," U.S. Patent Application, September 30, 2003, Navy Case # 84,597.
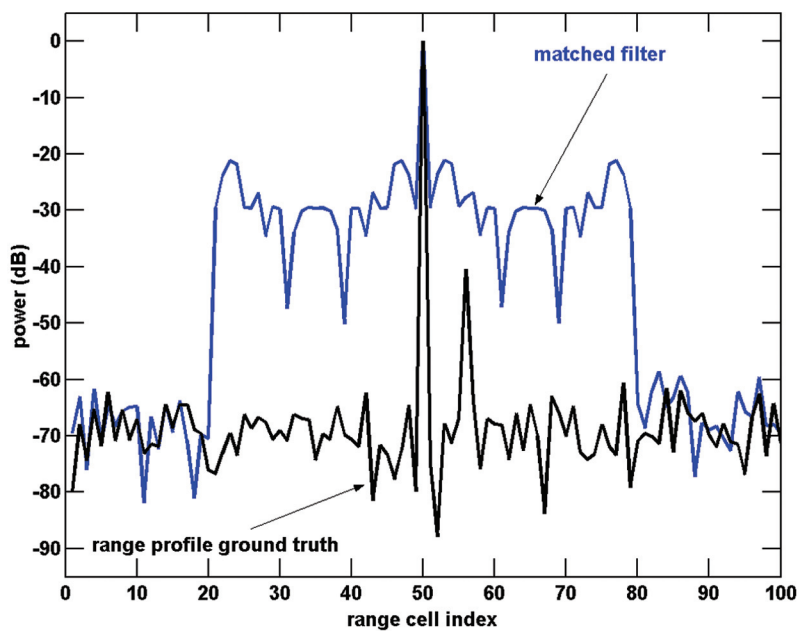
FIGURE 1
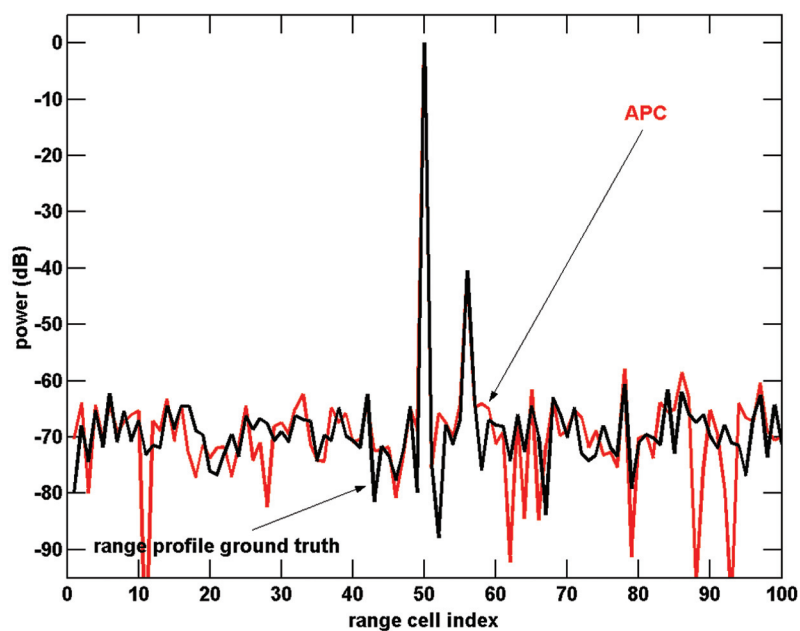Matched-filter output vs ground truth.
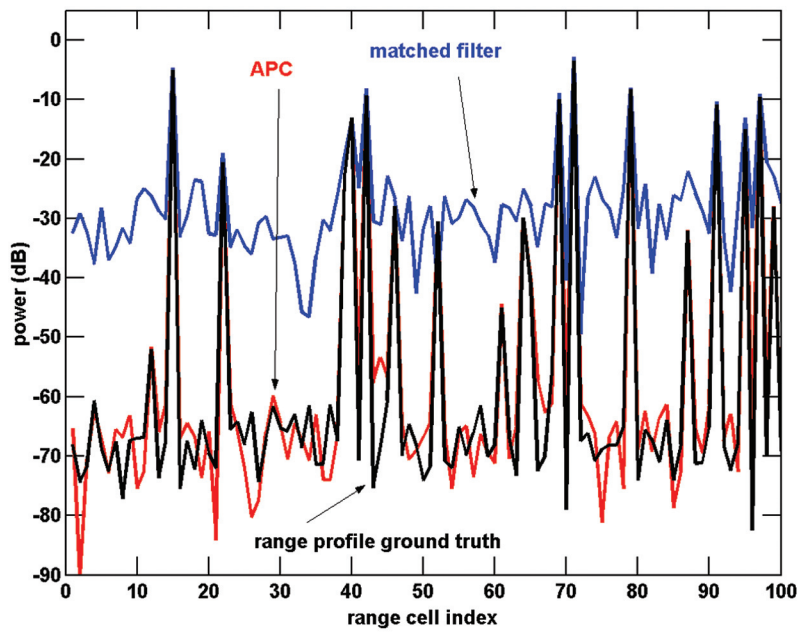

FIGURE 2
APC output vs ground truth.

FIGURE 3
Comparison of matched-filter and APC for a dense target environment.